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AN INTRODUCTION TO THE STUDY OF SOUTH AFRICAN RAINFALL.

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This paper is to be regarded as the fifth of the meteorological series planned some years ago, four of which have appeared in previous volumes of the *Transactions* of the South African Philosophical Society.

The following materials are available for a discussion of the rainfall of Kimberley:—

1. Monthly totals 1875, 1877–1902, by F. W. Matthews.
2. A complete daily register, 1884–1897, by the late G. J. Lee.
3. A complete daily register, 1880–1890, saving a gap in 1884, by the late L. and S. A. Exploration Company, taken for the Meteorological Commission; also nearly complete monthly totals from the same gauge, published in the Annual Reports of the Meteorological Commission, 1880–1900.
4. Monthly totals, 1885–1900, by the Gaoler, taken for the Meteorological Commission.
5. A complete register, 1894–1902, by J. R. Sutton.
6. Nearly complete returns within the last five years from gauges established at the different mines owned by the De Beers Company.
7. Occasional returns from various sources.

Of these the first is in many respects the most important, as it is the most extensive and complete. The record shows internal evidence of having been well and faithfully kept. The gauge has, however, what might be called a "roof" exposure, at an elevation of about 15 feet. This seems to have resulted in a small loss in the catch. Still an elevated gauge at Kimberley would not lose so great a percentage of the total fall as one at the same altitude in England, since our winds are lighter, and the average size of the raindrops much greater. Small droplets are readily carried by strong winds, as is proved by the "salt rain" (really sea spray) occasionally reported from different parts of inland England.* The Matthews gauge is a 5-inch Symons's early pattern.

No. 2 had also a roof exposure at nearly the same height. The gauge is an 8-inch Meteorological Office pattern. In earlier years the catch was entered to the ninth decimal place! This unique effort seems to have been accomplished by weighing the catch and converting ounces and grains into inches. But even if the mouth of the gauge had been accurately measured, the quantity of dust and rubbish collected would probably have been fatal to the trustworthiness of anything after the third decimal place. As a matter of experience, weighing is not to be recommended, with or without the extra decimals. "Weighing the water," said Horsley, "and reducing it from weight to depth, seemed pretty troublesome even when done in the easiest method." †

No. 3 is a Glaisher 8-inch gauge. Up to 1889, when the De Beers Company took over the business of the Exploration Company, it stood about 4 feet above the ground in a small courtyard behind the offices in Lennox Street. Now it is being used in the west end of Kimberley. I have some indistinct idea that the mouth of the gauge was said to be slightly too large, although it would be less surprising to be told that it had become too small, such being the certain ultimate fate of every gauge; for with a given perimeter a circle encloses the greatest area, and therefore any deformation of the rim of a gauge means a reduced area of catch. For a nice proof see Halsted, *Elements of Geometry*, p. 162.

Like a number of other gaols in the country, the rainfall reported by No. 4 is less than that reported outside. The inference that rain does not therefore fall upon just and unjust alike is plausible but incorrect. The true explanation is that the lighter rains are ignored by the observer.

No. 5 is an 8-inch ordinary gauge, mounted with its rim 3 feet above the ground. The observations with this have been supplemented by the hourly totals of rain caught in a large evaporation

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* See *e.g.*, *Phil. Trans.*, 1704, *passim*; Luke Howard, *Appendix to Barometrographia*, part 2, p. 16a.

† *Phil. Trans.*, 1723.

tank. These are generally too small as compared with the gauge, for reasons to a large extent obscure.

In consequence of the great local variation in the falls of rain, a number of 5-inch Snowdon gauges were set up in 1897 at the different mines and on some of the farms owned by the De Beers Company. The records were in many cases broken during the late war, and all the outside gauges taken away by the Boers. These gauges were all placed at the same height above the ground as the Kenilworth gauge, but they are mostly in a more open situation. This may be partly the reason why their catch is so frequently less than that of Kenilworth.*

Tables 1–12 give a complete history of rainfall at Kimberley from 1877–1902. The daily amounts for 1877, 1888, 1889, and part of 1884, were kindly given me by Mr. Matthews; 1880–1883, the remainder of 1884, with 1885, are from the Exploration Company's register; 1886–1897 are from the Lee register; 1898–1902 are from the Kenilworth register. Thus the history deals almost exclusively with the records of 8-inch gauges,† one half giving the rainfall near the ground, the other half at a height of 15 feet.

It has been usual at Kimberley to reckon the fall up to 8 a.m. on the last day of each month, entering the separate items to the date of measurement; but because it is preferable to give the fall up to 8 a.m. on the 1st of the following month, I have rearranged the monthly totals accordingly; and, so as not to disturb previous dates, made a rain month of 31 days extend from the 2nd to the 32nd. The totals in the last column of the historical Tables give the number of days, and the total fall for each date, in twenty-six years. If annual averages are required they may be obtained after division by 26.

It appears from these Tables that March is the wettest and July the driest month, the increase or decrease from one to the other being gradual. Although the total fall is less in February than in January, February is really the wetter month by an average of ·07 inch per day, on account of the fewer days it contains. There

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* The student may with profit consult Heberden, "On the different quantities of Rain which appear to fall at different heights, &c.," *Phil. Trans.*, vol. lix. p. 359 (1769); Barrington, "Experiments made . . . to ascertain the different quantities of Rain . . . at different heights," *Phil. Trans*, vol. lxi. p. 294 (1771); and chiefly, on the general question, Hann, *Lehrbuch der Meteorologie*, p. 296 Cleveland Abbe, "Determination of the true amount of Precipitation, &c.," *Bulletin No.* 7, *F. D.*, U.S.A. Dept. of Agr.; also G. Dines, "Difference of Rainfall with elevation," *British Rainfall* (1880). The other literature on the subject is of enormous bulk, and often amazingly futile.

† Not that the size of the gauge makes any appreciable difference.

seems, however, to be a distinct tendency to wet and dry seasons characteristic of certain seasons. For example, the first half of February and the second half of November are notably deficient in quantity; also the latter half of June, the latter half of September, the fourth week of October, and the first half of December, are relatively wet. The absolutely wettest time is during the last week of February; the driest during the first week of August.

Of the accidental variations we have some remarkable cases, due chiefly (probably) to the shortness of the record. A good example is found in the twenty-four hours ending at 8 a.m. February 9th. In the whole twenty-six years there was not a single shower on this date so great as ·10 inch, and indeed only one shower of any importance on the 10th; the total fall for the two dates together in the whole twenty-six years only reaching three-quarters of an inch. But as it happens the rule for dry weather at this time breaks down in the present year, 1903, with ·45 inch—a greater fall for the date than is furnished by all the former twenty-six years put together. Still it is curious, to say the least, that February 9th is the driest day, and February 9th and 10th the driest two days, in sixteen consecutive weeks. On the other hand, the rule for each of the four dates, February 25th–28th, is for heavy rain in every other year. Dates upon which no rain at all is known to have fallen are only found between June and September; albeit too much stress should not be laid upon the apparent dryness or otherwise of particular dates in any record extending over less than fifty years, because, for one reason, the total rain as given for any date is not materially greater than the possible rain in twenty-four hours. Take, for example, the rain of September 17th. This, for at least a quarter of a century, from 1877–1901, seemed to be one of the driest of days, only one small fall of ·015 inch being on record. In 1902 came a change with the heaviest day's rain known here (*i.e.*, 4·52 inches), making September 17th at one jump the wettest date in six months. This is a heavier fall than some rainfall maxims allow for. For example: "The extreme percentage of the mean annual rainfall which may be expected on any one day is, with a mean fall of 20 inches, 16 per cent. . . ." * For the same mean annual fall E. M. Eaton gives 20 per cent.† The Kenilworth fall in question is, however, nearly 25 per cent. of the annual mean. Moreover, in India there are stations where the fall in one day has exceeded the annual mean.‡

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* *British Rainfall*, 1867.

† *Symons's Met. Mag.*, 1878, p. 13.

‡ See Blandford, "Climates and Weather of India," pp. 64, 266.

The complete Matthews register of monthly totals is given in Table 13, and for comparison the yearly falls according to the Lee, Sutton, and Meteorological Commission registers. We may extract the following set of comparative annual averages :—

1877–1902 (26 years).	
By Tables 1–12	18·47 inches.
Matthews	17·81 ,,
1884–1897 (14 years).	
Matthews	18·08 inches.
Lee	18·53 ,,
Meteorological Commission	19·63 ,,
1894–1902 (9 years).	
Matthews	18·84 inches.
Sutton	18·99 ,,

It will be gathered from the comparative results of Table 13 that, even after making allowances for faulty exposure, the annual fall of one part of Kimberley may differ greatly from that of another. Thus in 1897 the fall at different gauges varied between a little more than 8·75 inches to a little less than 14 inches, most of the variation occurring in March. Also in 1902 the Kenilworth fall was upwards of 4·5 inches greater than that at the De Beers mine. The actual annual extremes shown by Table 13 range between 8·85 inches (in 1897 at Kenilworth) and 34·23 inches (in 1891 at the Exploration Company's gauge), a total range of more than 25 inches. This makes the maximum annual total nearly four times the minimum. There is, moreover, a register for Du Toit's Pan showing a much greater range, from 7·79 inches in 1878 to 37·46 inches in 1881, making the maximum nearly five times the minimum.* Without absolutely denying the truthfulness of these exceptional amounts, they should at any rate be received with caution. A minimum of 7·90 inches in 1892, reported from the Kimberley gaol, is undoubtedly too small, the number of rainy days being returned at twenty-nine!

It is interesting to compare the annual range of rainfall for Kimberley with that of some other places. Sir Charles Todd gives very full and clear information under this head for South Australia.†

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* *Report of the Met. Com.*, 1880, 1881.

† *Met. Obs. made at the Adelaide Observatory*, &c., 1899.

The following are worth attention:—

Port Darwin...............	42·44 inches	to	81·72 inches.
Alice Springs	5·39 ,,		27·21 ,,
Parallina	1·71 ,,		20·41 ,,
Adelaide	13·43 ,,		30·87 ,,

At Leon, Estado de Guanajuato, Mexico, the range is from 12·39 inches to 35·79 inches.*

At Algiers the range is from 17 inches to 51·45 inches.†

At Cordoba, Argentine, from 19 inches to nearly 40 inches.‡

In India we have Calcutta, with an annual average of about 65 inches, and a range from 38·5 to 98·5; Cawnpore, with an average of 32·3 inches, and a range from 7·1 to 60·7; Kurrachee, with an average of 7·6 inches, falling sometimes below half an inch, and rising sometimes to 28 inches; Bombay (Colaba), with an annual average of 74 inches, and a range of 79 inches from 35·9 to 114·9.§

At Durban the range is from 27·24 inches to 71·27 inches; at Port Elizabeth from 10·41 to 33·59; at Cape Town from 17 to 41.

Therefore, while the range at stations near the coast of South Africa is not materially different from that of other coasts, the range at Kimberley is relatively less than that of the inland stations of Australia and India, and greater than those of the interior of South America.

Table 14 has been designed to show the total rain of Tables 1–12 in twenty-four equal parts of a year of fifteen days each. To obtain this the total fall of February 29th has been increased in the ratio 5 : 26, there having been five leap-years in the period under review. The twenty-four quantities so obtained may be expressed in inches by the formula:—

$$\begin{aligned} R = 483{\cdot}024 &+ 18{\cdot}012 \sin (n15^\circ + 70^\circ) \\ &+ 4{\cdot}428 \sin (n30^\circ + 340^\circ{\cdot}8) \\ &+ 9{\cdot}764 \sin (n45^\circ + 339^\circ{\cdot}8) \\ &+ 2{\cdot}028 \sin (n60^\circ + 211^\circ{\cdot}4) \\ &+ \dots\dots\dots\dots \end{aligned}$$

The relative magnitudes of the third and fourth terms of this formula are worth notice.

Table 15 epitomises Tables 1–12, giving for each month the number

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* M. Leal, "Clima de Leon," *Mem. Soc. Alzate*, t. xii. p. 15.

† A. Thevenet, "Essai de Climatologie Algérienne."

‡ W. G. Davis, "Clima de Cordoba," *Anales Ob. Met. Arg.*, t. ix. (2) p. 299.

§ *Indian Met. Mem.*, vol. xiv.

of days of rain, and the average number per annum, in twenty-six years; the total fall in twenty-six years, and the annual average; the average per day, and the average per rainy day; the greatest fall on record, in one day, and one month; also the chance of a rainy day in any coming month. It seems that a fall exceeding an inch in twenty-four hours is not as a rule to be anticipated in June, July, or August, nor a month's rain exceeding 2 inches. The heaviest falls have occurred in the spring months, a single day's rain not infrequently making the month's total equal to that of the summer months. It is curious that the rate of fall should be greatest in September. There seems to be some indication of maximum rates at the equinoxes and solstices.

Table 16 gives the number of daily rainfalls of given quantity in the twenty-six years—the daily falls in 16A, and the monthly in 16B. It appears from this that upon nearly one-half the total of rainy days the fall is less than one-tenth of an inch. It must be remembered, however, that many of these small rains are associated in some way with the heavier falls, *i.e.*, they precede or follow wetter days. October is remarkable for the relatively great number of days upon which the fall is between ·5 inch and 1 inch. In September, on the other hand, it seems to be the rule for twice as many heavy falls above 1 inch as below. In fact, of the whole September fall of something less than 24 inches in twenty-six years, nearly 14 inches, or 58 per cent., fell in the seven days upon which the fall exceeded 1 inch per diem; whereas only 8·5 per cent. fell in the three days upon which the fall was between ·5 inch and 1 inch. In October more than 40 per cent. of the rain comes in showers of ·6 inch (more or less) each.

Some individual tendency to periodicity is indicated by rains of different intensity: good rains, say exceeding ·5 inch, have a maximum frequency in March and a minimum in July; which happens to be the case also for very light showers. But rains of between ·1 inch and ·5 inch have a maximum frequency in February and a minimum in August.

In Table 16B the most interesting month is October. In this month it is more than an even chance that the rain will be between 1 and 2 inches in amount. There is only one instance on record in which the rain for the month exceeded 2 inches, the excess falling in one day. The last column shows that in March and October the monthly rain is as often above the average as below.

There is not yet sufficient material available here to enable us to single out the rains of the different types from the ombrometric statistics. To do so successfully would require all the accumulated records of a weather bureau, although it may be possible later on to introduce some facts of interest in this connection. At present it may perhaps be taken as a working basis that the greater part of our rain falls in thunder-squalls and secondary cyclones, no great quantity coming in cyclones proper nor with straight isobars.

Table 17 gives the diurnal variation of rainfall at Kenilworth, in quantity and duration, both in whole totals for six years (1897–1902), month by month, and in annual averages. There was not a separate recording rain-gauge at this station during this period, and therefore the values have been mostly reduced from the automatic records of the evaporation tank. The yearly average quantities show a principal maximum at 4.30 p.m., and a principal minimum at 9 a.m.—being thus very nearly the inverse of the barometric phases. There are points of relationship with the diurnal oscillation of the barometer, as well as with the horary dewpoints. The phases of frequency are interesting because the maxima tend to fall earlier, and the minima later, than those of quantity. The last line of Table 17 gives the average fall for each hour of rain at different times in the day. This indicates that the rate of fall is lightest an hour or so after sunrise, and heaviest just before sunset, the increase of rate during the daylight hours being gradual. During the night hours there are considerable irregularities, with a strong tendency to a long-drawn-out maximum between XXIII. and III.

Table 18 shows the diurnal variation of rain for different seasons in portions of the total fall in six years; the total hours; and the average rate in each rainy hour. At the foot of the Table is given a summary showing how the seasonal variation is distributed between day and night, *i.e.*, from VI.–XVIII., and from XVIII.–VI., respectively. This proves that, saving the spring months (August–October), the greatest quantity of rain falls at night. In the summer it rains as often by night as by day; but in the winter there are half as many rainy hours again at night as there are by day. The rate of fall per rainy hour, however, is pretty much the same night and day, excepting in the spring. Putting all the seasons together, we find the quantity rather the greater at night, but the number of hours still greater, so that on the whole the rate of fall is greater by day.

Table 19 is inserted for comparison with Tables 17 and 18. It shows:—

1. Thunder and Thunderstorms.

2. Lightning unaccompanied by audible Thunder.
3. Thunder, Thunderstorms, and Lightning, all together.

The numbers are got from eye-observation. They cannot pretend to any completeness, particularly of lightning during the night. They show all that was seen or heard of this kind of electrical manifestation, but it is certain that many hours of it must have escaped notice. Still, they probably give a fairly good rough idea of the diurnal variation, at any rate between VI. and XXIV. A feature of special interest in the Table is the curious slackening in the frequency of thunderstorms between XVI. and XVII. Since thunderstorms evidently tend to a maximum about the time of sunset, we have at once a reason why the greatest rate of rainfall should come about this time.

Table 20 gives the most important harmonic constants in the diurnal curve of rainfall at Kenilworth, counting from 0h. 30m. a.m. The resemblance of the annual and semi-annual waves of both quantity and frequency to the same waves of barometric pressure inverted is very strikingly exhibited in the epochs. Attention should also be directed to the small fluctuation in the epoch of the second term of rain-frequency at all seasons, its departure from the mean never much exceeding half an hour. It is important to compare this fact with the resemblances between the corresponding terms of barometric pressure and vapour tension mentioned in previous papers of this series.* Seeing that there are not any mountains on the tableland to turn the horizontal air currents upwards, and that the air when it rises must do so of itself, the importance of this result in its bearings upon the theory of the semi-diurnal oscillation of the barometer will be obvious.

The amplitudes are of some interest. In the hours for the year the fourth harmonic term is practically as great as the third. But in the case of quantity the fourth is very much smaller than the third. Therefore the rainfall of six hours' period is very light. The first term is the greatest at all seasons, but the relative magnitude of the other three varies through the year. In the spring the second term almost vanishes, while the fourth term is large. In the summer the second term is large.

The harmonic constants of thunderstorms bear a strong family likeness to those of rain, particularly the summer frequency of the latter to the mean of the former. It is evident that a large proportion of the summer rain falls in thunderstorms, that of other classes being largely represented by the fourth term.

The diurnal variation of thunderstorms is probably a general

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* See "An Elementary Synopsis, &c.," *Trans. S. A. Phil. Soc.*, vol. xiv., p. 185.

phenomenon subject to local influences. For the purpose of comparison with the Kenilworth numbers I venture to quote the constants given by Riggenbach for Basle and Vienna.* Those for Basle are computed from hourly statistics of 1473 hours of thunderstorms observed between 1826 and 1888, supplemented by 171 others of which the duration and time of day is somewhat doubtful. Those for Vienna are quoted from Hann. Both the Basle and Vienna amplitudes are reduced to proportional parts of a thousand, the Kenilworth amplitudes are not. Riggenbach notes the near resemblance of certain of the phases of the two European stations. As it happens, the first two phases of the Kenilworth formula fall about as much later than Basle as Basle is than Vienna. Some correction, however, will have to be made for a departure from local time at Kenilworth of about seven minutes, the longitude of this place being about 24° 27′ E., while the time system is reckoned from the meridian of 22° 30′ E. Whether the Basle and Vienna constants refer to local or zone time I do not know.

It is important to determine in what manner particular wind-directions are associated with the monthly rainfalls. To do this, the monthly average number of hours of wind blowing in each direction during the six years 1897–1902 has been first determined from the automatic records taken at Kenilworth. The departures from these monthly means are then tabulated for each month, and it is also marked whether the concomitant rainfall is greater or less than the mean. Such departures of monthly wind-direction from the normals are then arranged into two sets according as the accompanying rain was greater or less than the normal rainfall. The result is condensed into Table 21, for each quarter of the compass. A plus sign indicates that in any set, for any month, there were more hours of wind than the average, a minus sign that there were less hours. For example, in January, with deficient rainfall, the number of hours of wind from N.–E.N.E. was thirteen hours short of the average; whereas when the rain was in excess the wind from the same quarter was twenty-four hours greater than the average. It appears from this that, taking the year as a whole, in the more rainy months the winds with an easterly component increase; those from the west increasing in dry months. In individual months there are some exceptions to the rule: in December, *e.g.*, a rainy month and an increase of wind from the north-west go together; in October the increase is from the south-west; in June and July the increase is with the winds having a southerly

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* A. Riggenbach, "Resultate aus 112 jährigen Gewitteraufzeichnungen in Basel," T. viii., 1889.

component. A miniature monsoon effect is suggested by this. For the greater part of the year our rain seems to be associated with surface winds having an easterly component; but during midwinter with surface winds from the south. This seems to furnish a link between the summer rains of Durban and the winter rains of the Cape Peninsula. At the same time two or three circumstances must be borne in mind: First, that it does not follow that these particular prevailing directions bring the rain, seeing that they may be as much an effect as a cause; second, that the cloud currents generally spring from points lying somewhere between north and west—clouds of the cirrus type coming more from the west, those of lower levels more from the north, of the mean direction; third, that as a rule the particular wind-direction associated with abundant rain, characteristic of any month, is the dominant normal wind of that month—that is to say, with abundant rain the normal prevailing wind prevails yet more; or, in other words, the rainfall decreases with the deviation of the vane from its normal position. This is a curious commentary on a previous result, "that, relatively to the normal curve, the cloudiness of the sky increases with the deviation of the vane from its normal position."* The cloud result, however, applies to the diurnal variation of the wind, while the rain result applies to the mean direction for the month. A noteworthy consideration is that whereas there were two months having a rainfall less than the mean to every one having a rainfall greater, in the six years under review, more deficient months have been included in forming the wind-averages than abundant ones, and therefore a certain amount of preconceived bias towards dryness has entered into the ratios. In passing it may be mentioned that the same bias is some drawback to the greater number of meteorological statistics in which one element has to be compared with another. It is not unlikely that deviations from the median, rather than from the mean, would give better comparative results.†

I have not yet made any experiments for the purpose of determining the temperature of falling rain, nor indeed do I yet know of a likely method.‡ But it may be roughly estimated, in proportionate numbers, from the consideration that in heavy falls the temperature of air, rain, and dewpoint, must tend to a common

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* "Winds of Kimberley, *Trans. S. A. Phil. Soc.*, vol. xi., pt. 1, p. 92.

† See Hann, "Handbook of Climatology" (Ward's edition), p. 24; Merriman, "Method of Least Squares," 8th ed., p. 210; Lupton, "Notes on Observations," 44.

‡ See, however, Hann, *Lehrbuch der Met.*, p. 303.

equality. Acting upon this principle the temperature of the dewpoint has been tabulated, in each month, at the end of any hour in which there was a rain exceeding ·10 inch. The results are arranged in Table 22 : Column 1 contains the months ; Column 2 the mean monthly temperature of the air for the five years 1898–1902 ; Column 3 the mean monthly temperature of the dewpoint ; Column 4 the mean temperature of the dewpoint immediately after rain, for each month ; Column 5 the frequency, *i.e.*, the number of observations from which Column 4 has been deduced. We may from these results form some idea of the altitudes from which the rain has fallen. For taking the adiabatic rate of cooling of the air as 1°·6 F. for each 300 feet of ascent, and the lowering of the dewpoint as 0°·3 for the same space due to the expansion of the air, we have this formula for the height h of the lower surface of the rain clouds—

$$h = 3000(t - d)/13,$$

where t is the normal temperature of the air and d that of the dewpoint after rain at the earth's surface.* Whence we get the relative heights of the rain clouds in Column 6. Of course these values can make no claim to any great precision, because while on the one hand the falling rain must notify the temperature of the air through which it passes, and thus also the mean temperature of the month, on the other hand it is certain that the rain mostly comes not so much from the cooling of ascending currents of moist air as from horizontal streams bringing moisture from the ocean. The average of Column 6 for the summer half, September to March, is 2,560 feet, that for the winter 1,060 feet. The August value, being obtained from only one observation, is of no great consequence. That October has a lower cloud level than either September or November is probably a fact, and may be directly connected with the absence of very heavy thunderstorms characteristic of that month, so plainly indicated in Table 16. Moreover, the October clouds tend, perhaps more than those of any other month, to a stratiform type, suggestive of the plane of contact of two humid air-strata at different temperatures.† The smallness of the April value is remarkable.

In the absence of direct measures the formula just quoted may be used for the purpose of approximately determining the altitudes at Kimberley of clouds generally. It gives a monthly average series ranging from upwards of 6,000 feet in November to 3,000 feet in April—this last value confirming the April minimum of Table 22. A useful development is a comparison between the mean monthly

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* W. M. Davis, "Elementary Meteorology," p. 163.

† See the remarks by F. Waldo, "Modern Meteorology," p. 255.

amounts of cloud and the corresponding computed mean altitudes of the lower plane of condensation. In Table 23 this is done in two ways: First, for each month of the five years 1898–1902 the mean monthly amount of cloud is tabulated in order of magnitude, followed by the corresponding computed altitude of the plane of condensation; next, the process is reversed, the computed altitudes being tabulated in order of magnitude followed by the corresponding amounts of cloud. For example, taking the mean results for January, we have in illustration of the first scheme:—

	Year.	Order.	Cloud.	Plane.
January	1898	A	59 per cent.	2,838 feet
	1899	B	45	5,538
	1900	C	38	5,331
	1902	D	31	5,123
	1901	E	30	6,438

And in illustration of the second—

	Year.	Order.	Plane.	Cloud.
January	1898	F	2,838 feet	59 per cent.
	1902	G	5,123	31
	1900	H	5,331	38
	1899	J	5,538	45
	1901	K	6,438	30

The double process is necessary because a particular month may have the same cloud percentage, but different cloud altitudes, in different years.

It appears from Table 23 that, generally speaking, the average altitude of the first plane of condensation will be greater as the cloudiness of the sky is less; and conversely. A moment's thought, and a glance at the Table, will show that this is not contradictory to the other result that the plane of condensation is lower in winter (when the percentage of cloud is small) than it is in summer (when the percentage of cloud is relatively great). The statement, however, is not a law in the sense that a great percentage of cloud necessarily implies a low cloud level. For obviously the prevailing cloud of any assigned month may be cirrus, or it may be stratus, or what not. But in the long run, when sufficient observations have been accumulated to give the averages their chance, the statement may be exact enough. As we might expect, then, in very dry weather the sky will be clearer than when there is much moisture in the air; and clouds, when they do form, must float at a much higher level.

Table 24 gives the mean annual complements of the dewpoint for each hour of the day, and the corresponding computed altitude of the first plane of condensation. According to this the diurnal variation ranges from about 2,000 feet at VI. to 7,000 feet at XV. The minimum altitude here may be somewhat too high, while the maximum is probably quite 400 feet too low. The Blue Hill observations show that up to about noon the computed and observed altitudes of cumulus, strato-cumulus, stratus, and nimbus, are not appreciably unlike; but after noon the observed altitudes become greater than the computed, reaching a maximum excess of 500 feet between XV. and XVI.* The explanation seems to be that the upward impetus of the warm air currents continues for some time after the temperature has begun to fall at the surface of the earth.

Table 24 gives also the monthly variation of the computed altitudes of the first plane of condensation at VI. and at XV. We see from this that the VI.-curve is the flatter, its amplitude being less by some 1,200 feet, and the actual minimum curve is flatter still. The greatest monthly mean computed altitude at either of the two selected hours in the five years considered was in November, 1900, with 10,250 feet, the least in April, 1899, with 690 feet, the former of course at XV. and the latter at VI. It may not be out of place to remark here that since the cloudiness of the sky only averages about 29 per cent., and the duration of sunshine is upwards of 76 per cent. of the optimum, the warm air currents do not in the majority of instances rise to the condensation level.

We have now to consider the position of Kimberley in the general scheme of South African rainfall. The principal published information suitable for this purpose will be found in the Annual Reports of the Meteorological Commission, where monthly totals and the maximum fall in each month only are given, derived from 300 (odd) gauges distributed throughout South Africa. The quality of the material is not of the best, although it has undoubtedly improved of recent years. Buchan has made a useful summary of the whole of the monthly totals printed in the reports of the ten years 1885–1894.† He deals with 278 stations, of which about one-half have a complete record; the other half having a shorter history of two to nine years.

Monthly averages for 160 stations having, generally speaking, com-

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* "Blue Hill Met. Obs.," in the *Harvard Annals*, vol. xlii., Part 1, p. 124. The discussion explains it the other way about.

† "A Discussion of the Rainfall of South Africa," 1897.

plete records for not less than seventeen or eighteen years, have been computed and arranged in Table 25. In the few instances made use of where the record is for a less number of years, the station is inserted because the area is badly represented or because of some importance in the site. The material comes chiefly from the pick of the annual reports of the Meteorological Commission for the years 1880–1901. Of the rest, the Kimberley record, as already mentioned, is from private registers; the Bloemfontein record was taken mostly from a register printed in a local newspaper; the Natal records are from the very excellent annual reports issued by the Durban Observatory, supplemented by some MS. monthly totals kindly sent me by Mr. Nevill.

In forming Table 25 I have availed myself largely of Buchan's work, simply combining in most of the cases his ten-year normals with the results for twelve additional years. This course was justified by an occasional test of the same normals. The rainfall areas I., II., III., IV., . . . of the Meteorological Commission's arrangement have been retained for the sake of continuity, although it is not easy to see why they were ever adopted.* The only attempted improvement has been to divide all the areas which seemed to extend too far east and west into two. A comparison between the Commission's map and its modification given at the end of this paper, together with an examination of the rainfall of some of the Karroo areas, will show the necessity for such a plan. Our subdivision raises the number of areas from fifteen to twenty. For each of these the mean rainfall has been computed, and approximate angles and coefficients in the sine series determined—only approximate because the months vary in length. These last appear in Table 26, wherein V_1, V_2, V_3 are the epochs; u_1, u_2, u_3 the amplitudes; u'_1, u'_2, u'_3 the amplitudes in parts per thousand of the mean monthly rainfall. We shall return to a consideration of these constants presently.

So far as these 160 stations go, Section I. (the Cape Peninsula) has the most copious fall, with an average of over 40 inches per annum; Section XV. (Natal) coming next with nearly 36 inches. The western division of Section IX. (Northern Border) is the most arid, with an average of less than 6 inches. It is to be remembered, however, that the sectional average results depend to a great extent upon the number of gauges in a given area, and their position. Generally the number of good records throughout

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* The latitudes, longitudes, and altitudes, are from the latest Reports of the Met. Com. Some of these are doubtful: Uniondale, Kleinpoort, and Glenconnor, in Section V., for example.

the Colony seems to vary directly as the intelligence of the population.*

Of the individual stations dealt with, Waai Kopje, on Table Mountain, has the most lavish rainfall. But there are stations close by with more. The absolutely wettest place known in South Africa is probably Maclear's Beacon, also on Table Mountain, with an average annual fall for the seven years 1894–1900 of 86·81 inches, and a variability from 69·14 to 105·85 inches per annum.† Particularly wet stations are Evelyn Valley, with an annual average of 59·50 inches; Hogsback, with 47·49 inches; Lower Katberg, with 43·20 inches; Perie Forest, with nearly 40 inches (these four are in Section X.); Ceres (Section II.), with 39·69 inches; Storms River (Section IV.), with 42·52 inches; stations in Basutoland (Section XIII.), with 30–40 inches; parts of Natal, with 40 inches more or less.

The driest station south of the Orange River seems to be Port Nolloth (Section III.), with only 2·5 inches per annum, ranging from ·45 inch to 5·35 inches. Other dry stations are: Garies, with 5·66 inches; Van Rhyn's Dorp, with 6·20 inches; Matjesfontein (Section VI. W.), with 6·33 inches; Middlepost (Section VIII. W.), with 5·20 inches; and all the stations forming Section IX. W., Pella being the most prominent, with 3·31 inches.

Of adjacent stations exhibiting great contrasts we have the Zwartberg Pass, 24·70 inches, a very few miles from Prince Albert, 9·15 inches; Alicedale, 16 inches, not far from Grahamstown, 27 inches; Evelyn Valley and Thomas River only 2′ of longitude and 3′ of latitude apart, and the rainfall of the former nearly three times that of the latter; and of course the various places in the Cape Peninsula. These last resemble, on a smaller scale, the contrasts between the wettest and driest parts of England.‡

With few exceptions the averages of Table 25 are less than Buchan's, the mean difference being probably at least 2 inches. Undoubtedly Buchan's normals include some particularly wet years.§

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* The lack of rainfall records in Natal until recently is remarkable, and does not confirm the generalisation. It must have been thought that because the best meteorological work in South Africa was being done at the Durban Observatory, potential observers were relieved of the responsibility of keeping registers.

† T. Stewart, "The Rainfall of the Cape Peninsula," a paper read before the S. A. Phil. Soc., Feb. 6, 1901.

‡ There does not seem to be any tendency in South Africa to a simple relationship between rainfall and altitude, as is sometimes found in more truly mountainous countries.

§ See also D. E. Hutchins, "Rainfall of S. Africa," in *C. G. H. Agricultural Journal*, Dec. 9, 1897.

Table 26 enables us much better than Table 25 to subdivide South Africa into suitable rainfall areas. Broadly these are—

1. Area of winter rains.
2. Area of summer rains.
3. Area of spring and autumn rains.

The characteristic formulæ of these give :—

1. $V_{\rm I} = 280°$, more or less; $u_{\rm I} > u_2$ or u_3.

Sections I., II., III., belong to this class.)

2. $V_{\rm I} = 60°\text{–}100°$; $u_{\rm I} > u_2$ or u_3.

(Sections XV., XIV., XIII., XII., XI., X., IX. E., VIII. E., VII. belong to this class.)

3. $V_{\rm I} = 180°$ or $360°$; $u_2 > u_3$ or $u_{\rm I}$.

(Sections IV. E., IV. W., V. W., VI. W., belong to this class.)

But there is not really any abrupt transition from one class to the other; and the formula representing any section bears a certain affinity to those representing the areas round about it. Near the west coast the formulæ change the most rapidly.

Let us first consider the variation of the epoch in $V_{\rm I}$ as the geographical position charges :—

Starting from Natal and travelling along the parallel of 30° S., we find that the angular magnitude of the epoch becomes smaller, *i.e.*, the phase times come later, from east to west. The variations are—

Area.	$V_{\rm I}$.	Approximate Epoch of Maximum.
Section XV.	101°·5	Jan. 4
XIII.	85°·8	Jan. 19
XIV.	77°·1	Jan. 29
IX. E.	67°·4	Feb. 7
IX. W.	54°·5	Feb. 20
III.	282°·0	July 5

Travelling west along a parallel somewhat to the north of 32° S., the variations are—

XII.	95°·8	Jan. 10
XI.	79°·2	Jan. 26
VIII. E.	67°·6	Feb. 7
VIII. W.	44°·1	Mar. 3
III.	282°·0	July 5

Travelling west along the parallel of 33° S., the variations are—

X.	95°·5	Jan. 10
VII.	77°·1	Jan. 29
VI. E.	66°·1	Feb. 9
VI. W.	19°·3	Mar. 28

But now we notice a remarkable fact. We have seen that the epochs come later as we travel east; they also come later as we travel northwards in the eastern districts; they also come later as we travel southwards in the western districts. Section XIII. is later than Section XII.; Section XIV. is later than Section X. But Section III. is earlier than Section I.; and Section IX. W., is earlier than Section VIII. W. It follows that the epoch of the first harmonic term is describing a curved orbit (if such a term may be permitted) with its concavity to the south. There is, for example, the following order:—

Area.	V_1.	Epoch of Maximum.
Section XV.	101°·5	Jan. 4
XII.	95°·8	Jan. 10
XIII.	85°·8	Jan. 19
XIV.	77°·1	Jan. 29
IX. E.	67°·4	Feb. 7
IX. W.	54°·5	Feb. 20
VIII. W.	44°·1	Mar. 3
VI. W.	19°·3	Mar. 28
V. W.	6°·5	April 10
IV. W.	329°·2	May 18

Fitting in with the same scheme are Sections X., VII., VIII. E., and Sections IV. E., V. E., VI. E., whose epochs come in corresponding sequence.

A similar line of inquiry with regard to the epoch of the second harmonic term shows either that the orbit is more complex, or that the monthly averages are not sufficiently near perfection to furnish the desired information. A general view seems to indicate that the path takes a direction from N.N.E. to S.S.W. across the tableland, curving eastward as it nears the south coast. The following are specimens:—

Area.	V_2.	Epoch of Maximum.	
Section XIII.	45°·1	Feb. 7	Aug. 9
XI.	23°·9	Feb. 18	Aug. 19
X.	313°·3	Mar. 26	Sept. 24

Area.	V_2.	Epoch of Maximum.	
Section XIV. …………	24°·5	Feb. 17	Aug. 18
VIII. E. ………	357°·5	Mar. 3	Sept. 2
VII. or VI. E.…	332°·0	Mar. 16	Sept. 15
V. E. …………	292°·9	April 5	Oct. 5
IV. E. …………	263°·8	April 20	Oct. 19
IX. E. …… ……	356°·2	Mar. 4	Sept. 3
VIII. W. ………	323°·5	Mar. 21	Sept. 19
VI. W. …………	276°·8	April 13	Oct. 13
V. W. …………	307°·7	Mar. 29	Sept. 27
IV. W. …………	281°·0	April 11	Oct. 11
IV. E. …………	263°·8	April 20	Oct. 19

Section VI. W. is the one apparent exception to the orderly sequence of dates in this arrangement. Yet it is to be observed that the Zwartberg Pass is in this Section. Now the monthly averages for this station are obtained chiefly from casual observations of rainfall in occasional months, regular observations only having been taken recently. A reference to Table 25 proves that the Zwartberg numbers, because of their great relative magnitude, have considerably influenced the averages of Section VI. W. The Matjesfontein results, however, are not of the highest excellence.

No very orderly scheme seems to include the angular magnitudes in V_3. They scarcely invite discussion, since much accuracy cannot be claimed for them.

The amplitudes u_1 decrease in absolute magnitude, latitude for latitude, from the coast inland. For example—

	u_1.		u_1.		u_1.
Section XV.…	2·494	Section XII. …	1·815	Section X. ……	1·285
XIII..	2·335	XI. ……	1·536	VII. …	·756
XIV…	1·702	VIII. E.	·988	VI. E…	·541
IX. E.	1·201	VIII. W.	·417	VI. W..	·151
IX. W.	·402	III. ……	·614	II. ……	1·395
III. …	·614			I. ……	2·524

This result does not mean, as might at first sight appear, that the amplitudes decrease with distance from the sea, because they actually tend to increase from south to north. The following are examples:—

	u_1.		u_1.		u_1.
Section X. …	1·285	IV. E.…	·155	IV. W.…	·147
XI.…	1·536	V. E. …	·169	V. W. …	·191

	u_{I}.		u_{I}.		u_{I}.
Section XIV.	1·702	VI. E.	·541	VI. W.	·151
		VII.	·756	VIII. W.	·417
		VIII. E	·988	IX. W.	·402
		IX. E.	1·201		

Here u_{I} is rather less in IX. W., than it is in VIII. W.—a result perhaps due to some affinity between these two Sections and Sections I., III. The amplitude in Section III. is considerably less than that of Section I.

Some of these results take a different aspect if we replace the absolute magnitudes of the first amplitude by the relative magnitudes. We then have—

	u'_{I}.		u'_{I}.		u'_{I}.
Section XV.	834	Section XII.	815	Section X.	537
XIII.	835	XI.	768	VII.	592
XIV.	875	VIII. E.	767	VI. E.	692
IX. E.	951	VIII. W.	561	VI. W.	135
IX. W.	824	III.	767	II.	738
III.	767			I.	749
X.	537	IV. E.	74	IV. W.	86
XI.	768	V. E.	167	V. W.	210
XIV.	875	VI. E.	692	VI. W.	135
		VII.	592	VIII. W.	561
		VIII. E.	767	IX. W.	824
		IX. E.	951		

Here VI. W. is again obtrusive. Making due allowance for it, it seems that there is a slight tendency to an increase inland along the parallels, which, however, is quite overridden by the strong increase inland along the meridians.

If the amplitudes of the first harmonic term be arranged along the orbit, as was done for the epochs, it appears that the absolute values gradually decrease, with, however, some little irregularity. The relative values, on the other hand, first increase and then decrease :—

	u_{I}.	u'_{I}.
Section XV.	2·494	834
XII.	1·815	815
XIII.	2·336	835
XIV.	1·702	875
IX. E.	1·201	951

	u_1.	u'_1.
Section IX. W.	·402	824
VIII. W. ...	·417	561
VI. W.	·151	135
V. W.	·191	210
IV. W.	·147	86

The following is the variation from east to west in the absolute amplitude of the second harmonic term:—

	u_2.		u_2.		u_2.
Section XV. ...	·112	Section XII.	·182	Section X.	·322
XIII. ...	·370	XI.	·404	VII. ...	·245
XIV. ...	·347	VIII. E...	·264	VI. E. .	·134
IX. E. .	·241	VIII. W..	·157	VI. W..	·218
IX. W..	·199	III.	·112	II. ...	·281
III. ...	·112			I.	·562

A remarkable feature about these amplitudes is that they tend to a maximum from the tableland side of the Drakensbergen southward to the sea. Thus the region of spring and autumn rains penetrates from the South Coast and Southern Karroo at least as far as the mountains of Basutoland. The reason why it cannot be easily detected in the monthly averages of Table 25 is that it is swallowed up by the great relative amplitude of the first term.

The corresponding values, in relative measure, are—

	u'_2.		u'_2.		u'_2.
Section XV. ...	38	Section XII.	82	Section X.	134
XIII. ...	132	XI.	207	VII. ...	192
XIV. ...	179	VIII. E.	206	VI. E.	171
IX. E.	191	VIII. W.	211	VI. W.	195
IX. W.	408	III.	140	II.	149
III. ...	140			I.	167

We are better able now to understand how it comes about that while nearly the whole of Sections IV. and V. have maxima of rainfall in autumn and spring, the western halves of both have the primary maximum in April or May, whereas the eastern stations have either a primary maximum or a greatly increased (relatively) secondary maximum in September. At first sight we should expect that the maxima of these eastern stations would approximate to those of the neighbouring Sections VII., VIII. E., and XI., rather than that the western stations should do so. But the explanation, as indicated above, is that the annual rain wave, becoming later and weaker as it journeys inland from the east coast, meets the south coast somewhere between Mossel Bay and Cape L'Agulhas in April, and reinforces the strongly marked semi-annual rain wave of the South Coast there, being scarcely felt at all further east.

It being fairly clear that the rains of Kimberley and Durban are included in the same system of summer rains, the extent of the relationship becomes an interesting question. Daily observations are published for the latter place, and therefore individual rains as well as monthly totals may be considered. Now it happens that there is not any real resemblance in the character of the showers of the two places. At Kimberley the heavier rain comes with a barometric depression; at Durban with a barometric crest. At Kimberley, speaking at large, the barometer rises as the heavy rain ceases; if there be more rain it is generally in small clearing showers. At Durban the barometer falls when the rain comes to an end. There were at Kimberley, in the five years 1897–1901, 72 heavy rains sufficiently isolated from other rain to admit of direct comparison with the pressures; at Durban there were 100 during the same period. By tabulating the barometric pressures of the days upon which the rain ended, for either place, together with three days before and two days after, we get the following comparative series of averages:—

	Durban.	Kimberley.
Third day before.........	30·075 inches	26·139 inches
Second ,, ...	30·061	26·131
First ,, ...	30·135	26·102
RAIN DAY	30·252	26·090
First day after...........	30·158	26·130
Second ,, ...	30·125	26·137

This is a result of considerable importance.

From a comparison of the monthly averages of Kimberley and Durban I have tried to determine whether a wet or a dry month at one place signifies a like or unlike state of things at the other. In Table 27 this has been done by tabulating in four columns:—

1. When the fall at both places is less than the mean.
2. When the fall at both places is greater than the mean.
3. When the fall at Durban is greater than the mean, but at Kimberley less.
4. When the fall at Durban is less than the mean, but at Kimberley greater.

The Table includes the twenty-six years 1877–1902—*i.e.*, 312 months. The two last columns show how many of these months had a fall less than the mean. It appears that there were 126 months in which both places together had a fall less than the mean; 53 in which the fall was greater than the mean at both; 63 in which the fall at Durban was greater, and at Kimberley less; 70 in which the fall at Durban was less, and at Kimberley greater. Is this anything more than chance? A perfectly chance distribution would give:—

When both stations together are less than the mean	119
When both together are greater	46
Durban greater and Kimberley less	63
Durban less and Kimberley greater	70

—the difference between the numbers in the last two lines evidently being a constant quantity. Thus there is an excess of 14 agreements greater than the 165 allowed for by the matured chances, which amounts to a deviation of both together in the same direction of about one month in the year. So that even if there be a relationship between these two stations it is not very decided.

Related more or less closely to the variation of rainfall is the cloudy state of the sky. This last element is stated in monthly averages in Table 28. Great accuracy must not be expected in these numbers, although they may possibly show the shape of the annual curves fairly well. It is a surprising fact that although the observation for the amount of cloud demands less skill than the reading of any instrument, it is done much more inaccurately. It is surprising sometimes how the percentage of cloud at a given station changes when the observer is changed; it is still more surprising how the observer himself sometimes changes. Kimberley observers have not on the whole made very comparable observations, as may be, *e.g.*, seen in the returns from Central Jones Street (G. J. Lee), and from the Meteorological Commission Station (C. Aburrow), for 1887.* That they may easily agree well enough is proved in the returns from Kenilworth, Kimberley (J. R. Sutton), and from Lennox Street (H. F. Harrison), for 1898.† Certainly the Kenilworth averages seem to be fairly consistent, as tested with the sunshine recorders. The following are the total percentages of sunshine *plus* cloud during daylight, year by year:—

1898	108 per cent.
1899	112
1900	111
1901	112
1902	110

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* *Report of the Met. Com.*, 1887.

† *Ibid.*, 1898.

The two earliest years had one observation of cloud in the morning and one in the afternoon; but the three later had two in the morning and two in the afternoon.* The Royal Observatory averages are also probably fairly good, since they agree on the whole with the Simonstown results. A change of method on the part of a single observer appears in the sudden drop in the estimated percentage of cloud at Graaff Reinet in 1892. For the nine years earlier than 1902 the average appeared as 39 per cent., varying from 35 per cent. to 44 per cent.; in the next seven it appeared as 16 per cent., varying from 12 per cent. to 21 per cent. But a new observer in 1900 immediately doubled this last low estimate. Defects being understood, we cannot always compare the cloudiness of one station with another, but only, sometimes, the annual variation at the same station.

From Table 28 I have selected a number of what seemed to be the best of the cloud averages, and determined the constants as far as the third harmonic term, putting in also the corresponding constants for rainfall, together with the rainfall constants for Adelaide and Alice Springs (South Australia), and Cordoba (Argentine). It is interesting to compare the South African numbers in this Table with those of Table 26, these being for stations, those for areas. The rainfall constants given here for Kimberley differ somewhat from those in the full formula computed above directly from Tables 1–12, for various reasons. The last are obtained from twenty-four nearly equal portions of a year. The values given in Table 29 (with the exception of Cordoba) are computed from the twelve months of various lengths reduced to thirty days. Thus the constants apply to the rate per month, rather than to aliquot parts of a year. The error introduced makes the times of the turning-points some four days too early in the first term, and seven days in the second. For comparative purposes only this is not of any great importance. In the third and later terms, however, the error is likely to be more serious. In the matter of the Cordoba numbers, the magnitudes given in "el Clima de Cordoba" are reckoned from January 1st. They are also determined from the average rainfall during each one-twelfth of a year. Before quoting them here they have been altered to count from the middle of January, so as to compare better with the others.

It appears from Table 29 that there is no very near approach to agreement between the epochs of cloud and rain for the different stations. At Durban, East London, and Kimberley the two elements

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* At Torquay, for the year 1899, the total percentage of (sunshine *plus* cloud) uring daylight is 104·4. A. Chandler, *Met. Rep. for* 1899.

tally fairly well. So do they also at Clanwilliam. At Aliwal North only in the annual term. At Simonstown the annual term of rainfall is a month earlier, and the semi-annual term a month later than the corresponding terms of cloud. Any correspondence at Port Elizabeth and Mossel Bay is only in the semi-annual terms. At the same time it seems not unlikely that the same annual cloud wave whose crest passes over Durban about the middle of December passes over Port Elizabeth and Mossel Bay a fortnight and five weeks later respectively, and a fortnight later still over Kimberley and Aliwal North. Nevertheless, it has lost its relative rank with respect to the second term by the time it reaches the south coast. It brings practically no rain, the annual wave of precipitation which started from the east coast with it not arriving until three months later.

Where do our rains originate? It has been stated pretty frequently and positively that they come from the south-east in summer and from the south-west in winter; that enormous quantities come from the South Indian Ocean in the summer, watering the greater part of the land south of the Zambesi; whereas the little that comes from the South Atlantic during the winter is all deposited within sight of Table Mountain.* One view connects them with the permanent anticyclones spreading across the ocean in these latitudes.† It is not clear, however, that such explanations represent all, or even more than a small portion, of the facts.

If these rains originate entirely in the south, it is indeed strange that practically all the cloud currents over Kimberley have a larger or smaller northerly component! Heavy thunder-clouds mostly advance from the west or north-west. Other rain clouds, and lighter thunderstorms, from somewhere between north-east and east. Scarcely any clouds come from the south-east, and very few from the south-west. The diurnal variation of the wind at Kimberley may be arrested, and the vane point for two or three days towards the south-east, and never a cloud obscure the sky. The variation may be arrested, and the vane point anywhere between east and north, and the sky be overcast and rain fall in abundance. And in almost every case the direction of the cloud movement is independent of the surface wind. One difficulty in settling such a question is paucity of observations: saving for one

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* Maury claimed that the rain of the world came chiefly from the southern hemisphere. The atmosphere "is an engine. The South Seas . . . are the boiler for it, and the northern hemisphere is its condenser" (*Physical Geography of the Sea* (1859), p. 52).

† Buchan, "Rainfall of South Africa," p. 16.

station, and that not under the control of the Meteorological Commission, we know next to nothing of the wind system of any place in Cape Colony. The statements that connect general wind changes with precipitation on the central tableland are probably misleading because they ignore the undetermined diurnal variation of the vane. So far as the coast stations are concerned it is still an open question as to the manner in which the wind-directions are modified by the great bulk of the tableland.

In the light of these drawbacks the numbers given in Table 30 must be discounted according to taste. They show, to the limits of our knowledge, the frequency and average fall of rain corresponding to particular wind-directions, at Durban, for the eighteen years 1885–1902, and at Kimberley for the nine years 1894–1902 (but reduced to eighteen years for purposes of comparison). The argument for Durban is the quantity of rain exceeding half an inch in twenty-four years for any day, and the wind direction at 9 a.m. entered to the same day. The Durban rain-day ends at 3 p.m. The argument for Kimberley is the quantity of rain for the twenty-four hours ending 8 p.m. on any day, and the wind-direction at 8 a.m. on the same day. Thus the wind is observed at the middle of the rain-day.

It appears from the Table that a south-west wind brings more rain to Durban than any other direction, the next most important direction being the south. A considerable quantity, also, falls in calms. Upon the whole, if we neglect calms, it may be affirmed that the rain winds of Durban tend to blow nearly parallel with the coast, the resultant direction being almost S.W. by S. The third most important direction is west. It is remarkable that so much should come from this point, which is directly from the considerable mountains of Basutoland.

At Kimberley the scheme is very simple. The resultant direction is appreciably from N. by E., practically nothing coming from any point having a south-westerly component.*

Thus two places not far from the same parallel of latitude, and in the same system of summer rainfall, have their chief rain-bearing winds from entirely opposite points of the compass. This result, however, is really what might have been expected from the opposite relationship to the variations of atmospheric pressure manifested by the rains of the two places. It seems to follow that the direction of the wind is only important in so far as it relates to the baric

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* If we observe the wind at 8 p.m. on the day before, *i.e.*, at the beginning of the rain-day, the resultant direction becomes nearly E. by N. This alteration is due to the influence of the diurnal oscillation of the vane.

gradients.[*] Now Prof. Morrison has pointed out that barometric depressions in most cases start from the south coast and travel in some northerly direction.

We may then summarise all that is known of the predominant conditions determining South African rainfall, outside the Cape Peninsula and West Coast, in the following paragraphs:—

The rain decreases on the whole with distance from the coast.

It comes with a high pressure at Durban, and a low pressure at Kimberley.

It comes chiefly with south-westerly winds at Durban, and with north-easterly winds at Kimberley.

The principal barometric disturbances come from the south.

The clouds over the tableland come from some northerly point.

We may be certain that the winds blowing on-shore along the west coast carry comparatively little moisture, not so much because of the short superoceanic path they are said to traverse (owing to the influence of the permanent anticyclone near by), as because of the coldness of the water.[†] An interesting parallel is found on the coast of California. It is referred to here because of the very apropos explanation it has elicited: "On the coast of Southern California the sea-breeze blows throughout the greater part of the year. It is weak in winter and strong in summer. During the latter season it is a dry wind even on the coast. . . . The cause is undoubtedly to be found in the fact that the ocean near the coast is very cool, while, on the other hand, the land is very much warmed. The air that comes off the ocean must therefore seem relatively dry over the land."[‡] The same argument holds with us, *mutatis mutandis.* Port Nolloth, on the west coast, with only 2·5 inches of rain per annum, is a far more humid place, because of its lower temperature, than Port St. John's, on the east coast, with a rainfall ten or twelve times greater. But Umtata, thirty-five miles inland from the east

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[*] It is interesting to compare these conditions with corresponding phenomena on the coast of Syria: "The barometer is *usually* on the rise during a rain. A south-west wind concurs with a rise from a low barometer." Moreover, "as long as the wind blows steadily from the west or south-west there is usually no rain. But when it blows for a day or two from the east, south, or south-south-west, and then veers suddenly to the west or south-west, rain is very apt to fall. (G. E. Post, "Notes on the Meteorology of Syria and Palestine," *Trans. Vic. Inst.*, vol. xx., pp. 284, 280.) At Manila the rain accompanies the depression, tending to its greatest rate of fall after the passage of the minimum pressure. (See Loomis, "Contributions to Meteorology." *Memoirs N.A.S.*, vol. iii., 1886.

[†] "The temperature of the sea near Cape Town is sometimes 20° lower than in the corresponding latitude on the eastern side of the continent" (Scott, *Elementary Meteorology*, p. 299, 6th Edition).

[‡] Hann's "Handbook of Climatology" (Ward's Edition), p. 156.

coast, is almost as humid as the coast, whereas O'okiep, fifty miles inland from the west coast, is exceedingly dry, and become so because the high temperature of the land as compared with the sea has lessened the relative humidity. This principle was known at end of the eighteenth century at least. Dalton has the following characteristically sagacious remarks upon the rainfall conditions of the north-west of England: "The reason that a S.W. wind in these parts brings rain seems to be that, coming from the torrid zone, it is charged with vapour, and the heat escaping as it proceeds northward, a precipitation of the vapour ensues; but a N.E. wind, blowing from a cold into a warmer country, has its capacity for vapour increased, and therefore we generally find it promote evaporation." *

The interpretation of these facts seems to be that our rain originates on the equator, being carried hither in the upper atmospheric currents flowing from the west and north. The rain begins on the east coast when this moist upper stratum meets the lower bodies of air damp with moisture from the Indian Ocean. Then it gradually works back from the east coast as the eastern air becomes heavier with vapour.†

Now the upper current, though it may be nearly saturated at its low temperature aloft, does not increase its absolute humidity by commingling with the air of the west coast, and therefore can flow across the slopes bordering the tableland without being induced to condense its moisture.

The copious rainfall of the district extending from Ceres to Table Mountain is perhaps largely promoted by its proximity to the region where the warm Agulhas and cold Benguela currents meet. Wojerkof mentions this cold current in connection with the aridity of the West Coast:—"An der Küste rührt diess zum Theil von der kalten Meeresströmung her, welche in der Nähe fliesst und von welcher aus kalte S.W.—und Süd Winde nach der Küste wehen. Die Passatwinde von der Ostküste kommen über das hohe Binnenland her schon in einem sehr trockenen Zustand an" ("Die Atmosphärische Circulation, &c.," in Erg. No. 38. Geo. Mitt. 1874).

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* Dalton, "Meteorological Observations and Essays," 2nd ed., 1834, p. 132.

† The month of greatest average rainfall over Natal is December (see Table 25), whereas the quantity of moisture in the air of Durban is greatest in February. At Durban itself, October, with a mean moisture of 5·8 grains per cubic foot, has as great a daily rainfall as February, with a mean moisture of 7·5 grains.